EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2026, 27(1), 199–206
https://doi.org/10.12912/27197050/215464
ISSN 2719–7050, License CC-BY 4.0

Received: 2025.11.24
Accepted: 2025.12.21
Published: 2026.01.01

Antibacterial and antifouling potentials of ethanol-aqueous extracts of *Ericaria amentacea* collected from the northwestern coast of Algeria

Schahrazede Lacheheb[1*], Smail Ali-Mehidi[1], Khadija Benchegra[1], Nadia Yasmine Asfouri[1], Mohammed Benyamina[1], Sid Ahmed Chawki Lamara[1], Sidi Mohammed El Amine Abi-Ayad[1]

[1] Aquaculture and Bioremediation Laboratory (AQUABIOR), Department of Biotechnology, Faculty of Science, University of Oran 1 Ahmed Benbella, Oran, Algeria
* Corresponding author's e-mail: Lachehebs2012@gmail.com

ABSTRACT

This work explored the antibacterial and antifouling properties of ethanol–water extracts from the brown macroalga *Ericaria amentacea*, collected along the northwestern Algerian coast. Extracts were prepared using maceration followed by ultrasonication. Antibacterial activity, assessed using the disk diffusion method, was most significant against *Escherichia coli* and *Listeria innocua*, with inhibition diameters measuring 20 ± 0.82 mm and 16.33 ± 0.46 mm, in that order, at a dose of 100 µg/mL. Moderate activity occurred against *Staphylococcus aureus*, *Listeria ivanovii*, and the yeast *Candida albicans*. In antifouling assays, the extracts significantly inhibited the growth of the diatom *Nitzschia* sp. at all tested concentrations, demonstrating a dose-dependent effect. The half-maximal effective concentration (EC_{50}) for the algal extract was 10.52 µg/mL, confirming potent bioactivity, although the synthetic biocide Diuron was more effective ($EC_{50} \leq 5$ µg/mL). These results position *E. amentacea* as a potential supplier of natural metabolites that can aid in producing eco-friendly antibacterial and antifouling agents.

Keywords: *Ericaria amentacea*, algal extracts, antibacterial activity, antifouling activity, northwestern Algerian coast.

INTRODUCTION

Brown macroalgae (Phaeophyceae) are vital components of coastal ecosystems and represent a promising resource for biotechnological applications. They form extensive underwater forests that serve as ecological hotspots, enhancing primary productivity, supporting biodiversity, and mitigating coastal erosion. Recent studies highlight their significant role in blue carbon processes, with kelp forests sequestering substantial amounts of CO_2 annually, often exceeding the capture rates of many terrestrial ecosystems (Eger et al., 2023; McHenry et al., 2025). This underscores their relevance in global carbon cycling, a point further emphasised by Qu et al. (2023).

Marine macroalgae are valuable reservoirs of biologically actives substances that can be exploited in fields such as pharmaceuticals, nutraceuticals, cosmetics, and environmental biotechnology (Pérez et al., 2016; El Hattab, 2020). Brown algae, in particular, have attracted growing significant scientific interest because of their distinctive chemical diversity and broad spectrum of biological activities. They synthesize numerous secondary metabolites, including phenolic derivatives (e.g., phlorotannins), terpenoids, polysaccharides, and fatty acids. These compounds play crucial ecological roles in defense against pathogens, herbivores, and biofouling organisms, while also holding considerable promise for biotechnological exploitation (Negara et al., 2021; Khan et al., 2022).

Within this group, species of the genus *Ericaria* are recognized to be abundant producers of diverse secondary metabolites exhibiting antimicrobial, antioxidant, and antifouling properties

(Oddo, 2020; De la Fuente et al., 2022). Their ecological and bioactive potential has been corroborated by recent investigations (Radman et al., 2022; Bouafir et al., 2025). *Ericaria amentacea* (C. Agardh) Molinari and Guiry, a dominant macroalgal taxa distributed along Mediterranean coasts (Thibaut et al., 2014; Bordoni et al., 2025), is increasingly studied for its ecological role and chemical composition. However, investigations into its bioactive potential, particularly concerning antibacterial and antifouling effects, remain limited, especially for populations inhabiting the western coast of Algeria.

The present work focuses on characterizing the antibacterial and antifouling potentiel of ethanol–water extracts obtained from the brown macroalga *Ericaria amentacea* harvested from the Algerian western coast. Specifically, it investigates the inhibitory effects of these extracts against selected microbial strains and assesses their impact on the growth of the marine diatom *Nitzschia* sp. The research also quantifies extraction yields and determines the half-maximal effective concentration (EC_{50}) to benchmark the bioefficacy of the algal extracts against that of a commercial biocide, Diuron. The findings aim to substantiate the potential of *E. amentacea* as a source of natural, eco-friendly compounds for antimicrobial and antifouling applications. The sustainable cultivation of this alga is proposed as an essential strategy to prevent the over-exploitation of this vulnerable species.

MATERIALS AND METHODS

Algal material and preparation

In March 2021, thalli of *Ericaria amentacea* were sampled from the western coastal zone of Algeria at a depth of one meter. The holdfast was left in place to encourage regrowth and minimize the impact of collection; only the apical and middle portions of the thalli were sampled. Plastic bags containing marine algae were stored on ice. Species identification was conducted using standard Taxonomic keys, with subsequent verification against the Algaebase database (www.algaebase.com), within the Laboratory of Aquaculture and Bioremediation. The samples underwent repeated rinsing in the lab with sterile seawater to eliminate sand particles and epiphytes. After two days of shade drying at room temperature (25 °C), they were further dried for 24 hours at a low temperature (30 °C) in an air circulating oven. Before further analysis, the samples were milled into a fine particulate and preserved at +4 °C.

Protocol for algal extract production

Extracts were prepared at serial concentrations (5 µg/mL, 10 µg/mL, 20 µg/mL, 25 µg/mL, 50 µg/mL, and 100 µg/mL). 50 g of dried matter brown algae was added and soaked in 100 mL of an ethanol-distilled water mixture (75:25) at 200 rpm for 3 hours protected from light at ambient temperature. Ultrasonication was performed with a Sonopuls HD 2070 homogenizer equipped with a UW 2070 converter (Bandelin Electronic GmbH & Co. KG, Berlin, Germany) at a fixed frequency of 20 kHz. Following ultrasonication (35% amplitude, 30 min), the mixture was spun at 5000 × g for 30 min at 4 °C (Sigma 3-18K). The clear phase was separated via filtration (Whatman No. 1), after which the liquid fraction was concentrated under reduced pressure at 40 °C (Hahnvapor HS-2005-N). The dried residues were dissolved in 2% DMSO, sterile-filtered (0.22 µm), and held at -20 °C.

Yield

The yield of the dry extracts is calculated using the following formula:

$$R\ (\%) = (P1 - P2) / P3 \times 100 \qquad (1)$$

where: $P1$ – the balloon's weight following evaporation; $P2$ – the flask's empty weight prior to evaporation; $P3$ – dry algal material weight.

Test microorganisms

Extracts of *E. amentacea* were tested at various concentrations against microorganisms: *Escherichia coli* (ATCC 22000), *Pseudomonas aeruginosa* (ATCC 27853), *Staphylococcus aureus* (ATCC 25923), *Listeria innocua* (ATCC 33090), *Listeria ivanovii* (ATCC 19119), *Candida albicans* (ATCC 26790) (provenance Algerian Pasteur Institut collection of AQUABIOR), and the diatom *Nitzschia* sp. *B10f-3* (Nantes Culture Collection, France).

Diffusion agar test

The antimicrobial activity of the derived solutions was assessed using the standard disc

diffusion assay, following established protocols (Balouiri et *al*., 2016). The test bacteria were standardised to a concentration of 10^8 CFU/mL (0.5 McFarland). Sterile 6 mm discs (Whatman No. 1) were loaded with 30 µL of each extract, with 2% DMSO serving as a negative control. The treated discs were then placed on Mueller-Hinton agar plates that had been swabbed with the bacterial suspensions. Post-incubation at 35 °C for 24 hours, the resulting halo sizes were measured in millimetres.

Culture of microalgae

Diatoms were aseptically cultured in a simplified seawater-based F/2 medium at 22 °C, with the media replaced every 15 days (Asfouri et al., 2017). Artificial seawater was synthesized from NaCl (30 g L^{-1}), $MgCl_2$ (10.2 g L^{-1}), and KCl (0.74 g L^{-1}), sterilized, and then enriched with Guillard's F/2 medium. The final culture medium was stored at 4 °C until required.

Evaluation of the activity of *Ericaria amentacea* extracts on the growth of microalgae

A volume of algae inoculum at a concentration of 10^5 cells per mL is spread on petri dishes containing a nutrient medium with varying concentrations of extracts (only concentrations showing effects were tested) or biocides. It is incubated at 22 °C under a natural light cycle. The effect is assessed using the method defined by Silkina et al. (2012), modified.

Seventy-two hours later, the effect of the extracts is evaluated by measuring chlorophyll a concentration through spectrophotometry. Post-extraction in methanol (99.8%, Sigma-Aldrich), supernatant absorbance was read at 652 and 665 nm to assess pigment concentration. These optical readings were then used to quantify chlorophyll a according to equation (2) (Qin et al., 2021). Cell counts are performed daily for three days using a Malassez-type hemacytometer under a microscope. On the fourth day, the cells are centrifuged at 2000 rpm for 10 minutes at 20 °C (sigma 3-18k). The culture medium is removed, and the cells are transferred to F/2 medium. Cell growth is then monitored daily for 8 days. The EC_{50} (concentration inhibiting 50% of algal growth) is calculated and expressed as a percentage of inhibition.

$$\%\ of\ inhibition = (Chl\text{-}a_C - Chl\text{-}a_t)/Chl\text{-}a_C \times 100 \quad (2)$$

where: $Chl\text{-}a_C$ corresponds to the chlorophyll a concentration of the control; $Chl\text{-}a_t$ corresponds to the chlorophyll a concentration of the strain tested in the presence of a given concentration of extract.

Synthetic biocide

A stock solution of the poorly water-soluble biocide diuron (N-[3,4-dichlorophenyl]-N, N-dimethylurea) was prepared using an organic solvent. Dimethyl sulfoxide (DMSO; 99%, Sigma-Aldrich) was selected as the carrier solvent based on established protocols, as it is miscible with water and has been reported to exhibit low toxicity towards diatoms (Bazes et al., 2009). A master stock solution of diuron was first prepared at 10 mg/ml in DMSO. Serial dilutions in sterile, double-distilled water were used to bring this stock into the culture medium, ensuring a final DMSO concentration of 0.2% (v/v) in all test solutions, as per a protocol adapted from Silkina et al. (2012).

Statistical analysis

Data are presented as mean ± SD (n = 3) for antibacterial tests and as duplicate measurements for inhibition of diatom tests. The statistical analyses were performed using Microsoft Office Excel 2016.

The concentration resulting in 50% growth inhibition (EC_{50}) was determined by linear regression in GraphPad Prism (v.10). Reported EC_{50} values are constrained to the experimental concentration range.

RESULTS

Yield

Ethanol aqueous *E. amentacea* extracts yield was 2.14±0.42%.

Antibacterial and antifungal assay

Table 1 shows that extract activity against bacteria and fungi depends strongly on the microorganism and the concentration applied.

Effect on Gram-negative bacteria

The inhibitory zone diameter of *E. coli* grew steadily with increasing extract concentrations, from 8±0.82 mm at 5 µg/mL to 20±0.82 mm at 100 µg/mL. However, *P. aeruginosa* exhibited complete resistance at all tested concentrations.

Effect on Gram-positive bacteria

L. ivanovii and *L. innocua* showed sensitivity to the extracts, with inhibitory zones increasing as concentration increased. While *L. ivanovii* exhibited reduced sensitivity, starting at 6±0.82 mm at 20 µg/mL and reaching only 9.33±0.94 mm at 100 µg/mL, the results for *L. innocua* ranged from 9.33±0.94 mm at 5 µg/mL to 16.33±0.46 mm at 100 µg/mL.

Staphylococcus aureus showed resistance at low to moderate concentrations, with inhibition observed only at the highest concentrations (9.33 ± 0.47 mm at 50 µg/mL and 11 ± 0.1 mm at 100 µg/mL).

Antifungal assay

At doses of up to 25 µg/mL, *Candida albicans* remained resistant; however, at doses of 50-100 µg/mL, inhibitory zones measuring 7 ± 0.1 mm and 8.67 ± 1.24 mm appeared.

Effect of *E. amentacea* extracts and diuron on the growth of *Nitzschia* sp.

The growth curves of *Nitzschia* sp. in the presence of *E. amentacea* extracts at various and efficacious doses (10, 20, 25, 50, and 100 µg/mL) and the reference biocide diuron are shown in Figure 1. In the control treatment, algal cell density steadily increased, reaching 270 × 10^5 cells/mL by day 8. In contrast, all concentrations of *E. amentacea* extracts significantly inhibited algal growth relative to the control. The level of inhibition was concentration-dependent: at the minimum tested dose (10 µg/mL), the inhibitory effect was minimal, with algal density reaching 250 × 10^5 cells/mL. At 20 µg/mL, growth was moderately reduced (238 × 10^5 cells/mL on day 8), whereas stronger inhibition occurred at 50 and 100 µg/mL, with final cell densities of 180 × 10^5 and 175 × 10^5 cells/mL, respectively. However, this inhibitory effect was lower than that of the reference biocide, which almost completely suppressed algal growth throughout the experiment. This was confirmed by the calculated EC_{50} value of 10.52 µg/mL for *E. amentacea* extracts. In contrast, diuron exhibited a much lower EC_{50} value (≤ 5 µg/mL).

On the other hand, we notice that once transferred to a new medium, the microalgae cultures exposed to brown algae extracts recover more slowly than the control culture, unlike those exposed to the commercial biocide, which do not return to a normal growth curve, demonstrating the toxic strength of the latter.

DISCUSSION

In this study, maceration, ultrasound, and centrifugation procedures using a green solvent mixture (ethanol-water) were employed to enhance overall yield and bioactive compound levels from *E. amentacea* (Azmir et *al*., 2013; Castillo et *al*., 2023). Recent works have reinforced the efficiency of ultrasound- and microwave-assisted techniques as advanced approaches for optimizing the isolation of bioactive compounds (Taherkhani et *al*., 2024).

The antibacterial test showed that the plant extracts exhibited good activity against *E. coli* (20 ± 0.82 mm) and *L. innocua* at 100 µg/ml and moderate inhibition on *S. aureus* (11 ± 0.1 mm) and *L. ivanovii* (9.33 ± 0.94 mm) at the same concentration.

Table 1. Antibacterial and antifungal activity of ethanol–aqueous extract of *Ericaria amentacea*

Concentration (µg/mL)	*E. coli*	*L. innocua*	*L. ivanovii*	*P. aeruginosa*	*S. aureus*	*C. albicans*
5	8 ± 0.82	9.33 ± 0.94	R	R	R	R
10	8.33 ± 0.94	11 ± 0.82	R	R	R	R
20	9.67 ± 0.47	11.67 ± 1.25	6 ± 0.82	R	R	R
25	10 ± 0.10	12.67 ± 0.94	6.33 ± 0.46	R	R	R
50	14.33 ± 0.47	13.67 ± 0.47	9 ± 0	R	9.33 ± 0.47	7 ± 0.10
100	20 ± 0.82	16.33 ± 0.46	9.33 ± 0.94	R	11 ± 0.10	8.67 ± 1.24

Note: Zones of inhibition are expressed in mm ± SD. R = resistant (no inhibition).

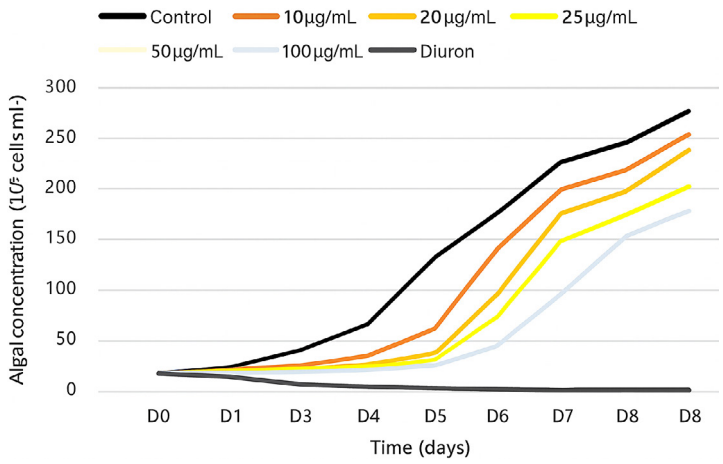

Figure 1. Growth response of *Nitzschia* sp. under exposure to increasing concentrations of *Ericaria amentacea* extracts and diuron (mean ± SD, n = 2)

However, no inhibitory effect was observed against *P. aeruginosa. C. albicans* yeast displayed the greatest inhibition at 100 µg/ml, with only 8.67 ± 1.24 mm. De la Fuente et *al*. (2022) reported results with the methanol/dichloromethane extract of *E. amentacea*, showing 87% inhibition against *S. aureus* and 27% against *C. albicans*.

The resistance exhibited by *P. aeruginosa* likely results from its lipopolysaccharide-rich outer membrane, which hinders the penetration of molecules, including antibiotics (Piacenza et *al*., 2017). Maggio et *al*. (2020) specified that the methanol-water extract of *E. amentacea* inhibited the Gram-positive strain *S. aureus* but had no effect on the Gram-negative strain *E. coli*. The same author mentioned that this species contained the highest amount of phenol, particularly fukiic acid and bromophloroglucinol, which may be responsible for this activity. Yong-Xing Li et al. (2011) noted that the antibacterial efficacy of phlorotannins is influenced by factors such as molecular weight, and Wang et *al*. (2009) revealed that their antibiotic effect may be both bactericidal and bacteriostatic. Mirata et *al*. (2023) and Radman et *al*. (2022) also documented that Mediterranean populations of *E. amentacea* are rich in phenolic compounds, which confer antioxidant and photoprotective properties. The levels and bioactivity of these metabolites are strongly shaped by environmental parameters, such as light, temperature, and nutrient supply (Lopes et *al*., 2024). Mannino et *al*. (2016) observed a seasonal trend in total phenolic compounds, with peak levels occurring during winter and spring in *E. amentacea*.

Oucif et *al*. (2017) observed a phenolic content of 8.24 ± 0.89 and 4.36 ± 0.21 mg GAE g^{-1} DW in the methanol and ethanol extracts of *E. amentacea* collected on the west coast of Algeria. This alga is considerably richer in antioxidant compounds compared with TPC content (De la Fuente, 2020). In contrast, the ethanol extract of the brown algae *Cystoseira compressa* inhibited *S. aureus* (29±0.00) but did not affect *P. aeruginosa* (Leibirsh et *al*., 2020). Tajbakhsh et *al*. (2011) mentioned that a combination of diethyl ether, ethanol, and hexane extracted from *C.trinodis* stopped the expansion of *E. coli*, *S. aureus*, and *P. aeruginosa*.

Sayin et *al*. (2021) recorded that the methanol extract of *E. amentacea* exerts both inhibitory and bactericidal effects toward *E. coli*, *S. aureus*, and *P. aeruginosa*. Our results align with those revealed by Erturk et *al*. (2011) and El Wahidi et *al*. (2015), who used ethanolic extracts of *Padina pavonica*, *C. barbata*, and *C. compressa* to test against *S. aureus*, *E. coli*, *L. monocytogenes*, and *C. albicans*.

Lopes et *al*. (2013) extracted phlorotannins from *C. nodicaulis* using hexane, followed by an acetone-water mixture, and observed an inhibitory effect against *C. albicans* (MIC = 15.6). Conversely, Vimala and Poonghuzhali (2017) noted that the ethyl acetate extract of the brown algae *Hydroclathrus clathratus* demonstrates the maximum activity against *C. albicans* (18.14 ± 1.50 mm). Cox et *al*. (2010) found that methanol extracts from various brown seaweeds inhibit *L. monocytogenes* and *P. aeruginosa*.

Extraction solvents play a vital role in isolating compounds from algae. Ethanol and its aqueous mixtures are the most suitable solvents for

extracts targeted for use in pharmaceutical, food, or cosmetic industries (Generalic-Mekinic, 2019).

The yields of obtainable and antibacterial compounds from several seaweed species vary depending on the solvent used (Pérez et *al*., 2015).Some studies suggest that polar extracts generate extracts with enhanced antibacterial effects. *Yoon* et *al*. (2017) found that edible brown seaweed *E. cava* produced the highest amount of phlorotannins when extracted with 95% ethanol. Other research confirms that combinations of hydrophilic solvents and/or alcohol-based solutions offer improved efficacy (Krish et *al*., 2014; De Jesus Raposo et *al*., 2015). Honey et *al*. (2024) reported that using multiple solvents of varying polarities for the same extraction would likely increase the antimicrobial inhibitory effect.

The antimicrobial activity of algae can be shaped by a range of factors, notably habitat, developmental stage, algal conditioning, extraction method, season of collection, activity of biofoulers and grazers, and pollution (Silva et *al.*, 2020; Emeline et *al*., 2021), among others, which may explain the differences in findings reported by different researchers. Brown algae were the most extensively studied macroalgae. Their effects were primarily antibacterial, including anti-quorum-sensing, with additional activities such as anti-algal, anti-diatom, and anti-larval actions (Dahms et *al*., 2017; Lemesheva et *al*., 2023).

In our study, *E. amentacea* significantly reduced Nitzschia growth at all tested concentrations without causing any harmful effects, with an EC_{50} of 10.52 µg/mL. In contrast, diuron shows irreversible inhibition of diatom growth at the minimum tested dose (5 µg/mL), preventing the determination of its EC_{50} and confirming its extremely high toxicity. Moraes et al. (2019) indicated that a widespread inability to pick new drug candidates should have greater than 50% inhibitory activity at a concentration below 30 µM.

The majority of the activity-bearing active components were uncharacterised; however, they were mainly isolated with polar alcohol-based extracts (Negara, 2021). The methanol extract of the brown algae *C. mediterranea* showed significant antifouling activity. The main compounds in this extract were fatty acids and steroids (Ibrahim et *al.*, 2019). Therefore, Bazes et *al*. (2009) indicated that palmitic acid, which is commonly found in algae, exhibits notable inhibitory activity against the diatom *Closterium* (CE_{50} = 45.5 µg/mL). Oucif et *al*. (2019) reported a palmitic acid content of 28.70 ± 0.74 g/100 g in *E. amentacea* from Algeria's west coast. Silkina et *al*. (2012) confirm the sensitivity of diatoms (*F. pinnata*, *C. closterium*, and *T. pseudonana*) exposed to ethanol extracts of a pheophyceae (*Sargassum muticum*) and a rhodophyceae (*Ceramium botryocarpum*), with growth EC_{50} values of 4.74 and 5.3 µg/mL, in that order, and a temporary effect on diatom cell division. The authors indicate that biocides were more effective (EC_{50} = 0.52 µg/mL) but potently toxic.

CONCLUSIONS

Marine seaweeds are increasingly recognized as sources of biologically active compounds. Extracts from *E. amentacea* demonstrate antibacterial, therapeutic, and antimicroalgal properties. They effectively inhibit *E. coli* and *L. innocua*, while showing moderate activity against *S. aureus*, *L. ivanovii*, and *C. albicans*. Conversely, *P. aeruginosa* was resistant.

All tested concentrations of *E. amentacea* significantly inhibited algal growth compared to the control. However, this inhibitory effect was reversible and less effective than the reference biocide, which nearly eliminated algal growth throughout the experiment. Although less potent than diuron, *E. amentacea* extracts provide a promising eco-friendly alternative because of their biodegradability and likely reduced harm to non-target organisms.

Acknowledgments

The authors would like to thank the Aquaculture and Bioremediation Laboratory (AQUABIOR) for the facilities provided.

REFERENCES

1. Asfouri, N. Y., Djalt, H. S., Maroc, F., Lamara, S.-A. C., Baba Hamed, M. B., Abi-Ayad, S.-M. E.-A. (2017). Cultivation of marine microalga *Nannochloropsis gaditana* under various temperatures and nitrogen treatments: Effect on growth, lipid, and pigment content. *International Journal of Biosciences, 10*(3), 209–216. https://doi.org/10.12692/ijb/10.3.209-216
2. Azmir, J., Zaidul, I. S. M., Rahman, M. M., Sharif, K. M., Mohamed, A., Sahena, F., Jahurul, M. H. A., Ghafoor, K., Norulaini, N. A. N., Omar, A. K. M. (2013). Techniques for extraction of bioactive compounds from plant materials: A review. *Journal of Food Engineering, 117*(4), 426–436. https://doi.org/10.1016/j.

jfoodeng.2013.01.014

3. Balouiri, M., Sadiki, M., Ibnsouda, S. K. (2016). Methods for in vitro evaluating antimicrobial activity: A review. *Journal of Pharmaceutical Analysis, 6*(2), 71–79. https://doi.org/10.1016/j.jpha.2015.11.005
4. Bazes, A., Silkina, A., Douzenel, P., Faÿ, F., Kervarec, N., Morin, D., Berge, J.-P., Bourgougnon, N. (2009). Investigation of the antifouling constituents from the brown alga *Sargassum muticum* (Yendo) Fensholt. *Journal of Applied Phycology, 21*(3), 395–403. https://doi.org/10.1007/s10811-008-9382-9
5. Bordoni, R., Paoli, C., Asnaghi, V., Chiantore, M., Farina, L., Gaino, F., Rigo, I., Ruggeri, F., Vassallo, P. (2025). Habitat suitability models as a prioritization tool for enhancing the restoration success of *Ericaria amentacea*. *Ocean & Coastal Management, 270*, 107892. https://doi.org/10.1016/j.ocecoaman.2025.107892
6. Bouafir, Y., Bouhenna, M. M., Nebbak, A., Belfarhi, L., Aouzal, B., Boufahja, F., Bendif, H., Bruno, M. (2025). Algal bioactive compounds: A review on their characteristics and medicinal properties. *Fitoterapia, 182*, 106591. https://doi.org/10.1016/j.fitote.2025.106591
7. Castillo, A., Celeiro, M., Lores, M., Grgić, K., Banožić, M., Jerković, I., Jokić, S. (2023). Bioprospecting of targeted phenolic compounds of *Dictyota dichotoma*, *Gongolaria barbata*, *Ericaria amentacea*, *Sargassum hornschuchii* and *Ellisolandia elongata* using green extraction. *Marine Drugs, 21*(2), 97. https://doi.org/10.3390/md21020097
8. Cox, S., Abu-Ghannam, N., Gupta, S. (2010). An assessment of the antioxidant and antimicrobial activity of six species of edible Irish seaweeds. *International Food Research Journal, 17*(2), 205–220.
9. Da Silva, C. M., da Silva, D. L., Modolo, L. V., Alves, R. B., de Resende, M. A., Martins, C. V., de Fátima, Â. J. (2011). Schiff bases: A short review of their antimicrobial activities. *Journal of Advanced Research, 2*(1), 1–8. https://doi.org/10.1016/j.jare.2010.05.004
10. Dahms, H. U., Dobretsov, S. (2017). Antifouling compounds from marine macroalgae. *Marine Drugs, 15*(9), 265. https://doi.org/10.3390/md15090265
11. De Jesus Raposo, M. F., De Morais, A. M. B., De Morais, R. M. S. C. (2015). Marine polysaccharides from algae with potential biomedical applications. *Marine Drugs, 13*(5), 2967–3028. https://doi.org/10.3390/md13052967
12. De La Fuente, G., Fontana, M., Asnaghi, V., Chiantore, M., Mirata, S., Salis, A., Damonte, G., Scarfì, S. (2021). Antioxidant and anti-inflammatory potential of *Cystoseira amentacea var. stricta*. *Marine Drugs, 19*(1), 2. https://doi.org/10.3390/md19010002
13. De La Fuente, G., Pinteus, S., Silva, J., Alves, C., Pedrosa, R. (2022). Antioxidant and antimicrobial potential of six fucoids from the Mediterranean and Atlantic. *Journal of the Science of Food and Agriculture, 102*(12), 5568–5575. https://doi.org/10.1002/jsfa.11944
14. Eger, A. M., Layton, C., Edwards, M., Hernández, C. A., Krumhansl, K. (2023). The economic and ecological value of ecosystem services from kelp forests. *Nature Communications, 14*, 2321.
15. El Hattab, M. (2020). *Algae Essential Oils: Chemistry, Ecology, and Biological Activities*. IntechOpen. https://doi.org/10.5772/intechopen.91672
16. Emeline, C. B., Ludovic, D., Laurent, V., Catherine, L., Kruse, I., Erwan, A. G., Florian, W., Philippe, P. (2021). Induction of phlorotannins in *Fucus vesiculosus*. *Marine Drugs, 19*(4), 185. https://doi.org/10.3390/md19040185
17. El Wahidi, M., El Amraouia, B., El Amraouia, M., Bamhaouda, T. (2015). Screening of antimicrobial activity of macroalgae extracts from the Moroccan Atlantic coast. *Annales Pharmaceutiques Françaises, 73*(3), 190–196.
18. Erturk, O., Tas, B. (2011). Antibacterial and antifungal effects of some marine algae. *Kafkas Universitesi Veteriner Fakultesi Dergisi, 17*(Suppl A), S121–S124.
19. Generalić Mekinić, I., Skroza, D., Šimat, V., Hamed, I., Čagalj, M., Popović Perković, Z. (2019). Phenolic content of brown algae. *Biomolecules, 9*(6), 244. https://doi.org/10.3390/biom9060244
20. Honey, O., et al. (2024). Antioxidant and antimicrobial potential of three common seaweeds. *Journal of Umm Al-Qura University for Applied Sciences*. https://doi.org/10.1007/s41208-025-00856-w
21. Ibrahim, H. A. M., El-Sayed, H. S., El-Sayed, S. M., El-Naggar, M. M. (2019). Antifouling activity of some seaweed extracts from the Red Sea. *Egyptian Journal of Aquatic Biology and Fisheries, 23*(3), 435–445. https://doi.org/10.21608/ejabf.2019.45962
22. Khan, F., Jeong, G.-J., Khan, M. S. A., Tabassum, N., Kim, Y.-M. (2022). Seaweed-derived phlorotannins: A review. *Marine Drugs, 20*(6), 384. https://doi.org/10.3390/md20060384
23. Krish, S., Das, A. (2014). In-vitro bioactivity of *Cladophora rupestris*. *International Journal of Pharmacy and Biological Sciences, 5*(4), 898–908.
24. Lemesheva, V., et al. (2023). Antibacterial, antifungal and algicidal activity of phlorotannins. *Plants, 12*(4), 821. https://doi.org/10.3390/plants12040821
25. Li, Y. X., Wijesekara, I., Li, Y., Kim, S. K. (2011). Phlorotannins as bioactive agents from brown algae. *Process Biochemistry, 46*(12), 2219–2224. https://doi.org/10.1016/j.procbio.2011.09.015
26. Lopes, C., et al. (2024). Abiotic factors modulating metabolite composition in macroalgae. *Marine Drugs, 22*(12), 544. https://doi.org/10.3390/md22120544
27. Lopes, G., Pinto, E., Andrade, P. B., Valentão, P. (2013). Antifungal activity of phlorotannins against

dermatophytes. *PLOS ONE, 8*(8), e72203. https://doi.org/10.1371/journal.pone.0072203

28. Maggio, A., et al. (2020). Antibacterial activity of Mediterranean brown algae. *Plant Biosystems, 154*(1), 43–50. https://doi.org/10.1080/11263504.2020.1829737
29. Mannino, A. M., Vaglica, V., Cammarata, M., Oddo, E. (2016). Temperature effects on phenolics in *Cystoseira amentacea*. *Plant Biosystems, 150*(1), 152–160.
30. McHenry, J., Brodie, J., Vergés, A., Smale, D. A. (2025). Blue carbon assessment in kelp forests. *Nature Reviews Earth & Environment, 6*, 125–138. https://doi.org/10.1038/s44183-025-00125-6
31. Mirata, S., Riba, M., Pagès, T., Valls, R., Sureda, A. (2023). Photoprotective properties of *Ericaria amentacea*. *Marine Drugs, 21*(5), 306. https://doi.org/10.3390/md21050306
32. Molinari, E., Guiry, M. D. (2020). *Ericaria amentacea* (C. Agardh) Molinari & Guiry. AlgaeBase. https://www.algaebase.org
33. Moraes, C. B., et al. (2019). Integrated drug discovery platform. *SLAS Discovery, 24*(3), 346–361. https://doi.org/10.1177/2472555218823171
34. Negara, B. F. S. P., et al. (2021). Antifungal and larvicidal activities of phlorotannins. *Marine Drugs, 19*(4), 223. https://doi.org/10.3390/md19040223
35. Oddo, E. (2020). Antibacterial activity and HPLC analysis of Mediterranean brown algae. *Plant Biosystems, 154*(1), 43–50. https://doi.org/10.1080/11263504.2020.1829737
36. Oucif, H., Benaissa, M., Ali Mehidi, S., Prego, R., Aubourg, S. P., Abi-Ayad, S. M. E. A. (2017). Chemical composition and nutritional value of seaweeds from the West Algerian coast. *Journal of Aquatic Food Product Technology, 26*(9), 1133–1145. https://doi.org/10.1080/10498850.2017.1385993
37. Oucif, H., Benaissa, M., Ali Mehidi, S., Prego, R., Aubourg, S. P., Abi-Ayad, S. M. E. A. (2019). Chemical composition of seaweeds from the West Algerian coast. *Journal of Aquatic Food Product Technology, 29*(1), 90–104. https://doi.org/10.1080/10498850.2019.1695305
38. Park, S. Y., Kim, E. J., Lee, J. H., Cho, Y. S. (2023). Polysaccharides from brown seaweed. *Marine Drugs, 21*(6), 345. https://doi.org/10.3390/md21060345
39. Pérez, M. J., Falqué, E., Domínguez, H. (2016). Antimicrobial action of compounds from marine seaweed. *Marine Drugs, 14*(3), 52. https://doi.org/10.3390/md14030052
40. Piacenza, E., et al. (2017). Antimicrobial activity of Se-nanomaterials. *Microbial Biotechnology, 10*(4), 804–818. https://doi.org/10.1111/1751-7915.12700
41. Qin, H., Li, S., Li, D. (2021). An improved method for determining chlorophyll *a*. *Journal of Applied Phycology, 33*(2), 1257–1265. https://doi.org/10.1007/s10811-020-02335-6
42. Qu, T., Gao, X., Xu, L., Wang, Z. (2023). Regional variability in carbon storage potential of kelp forests. *Ocean & Coastal Management, 238*, 106563. https://doi.org/10.1016/j.ocecoaman.2023.106563
43. Radman, S., et al. (2022). Bioactivity of *Ericaria crinita* and *E. amentacea*. *Marine Drugs, 20*(1), 57. https://doi.org/10.3390/md20010057
44. Sayın, S., Aydın, B., Ak Çimen, B., Açık, L. (2021). Antimicrobial effects of marine macroalgae from Iskenderun Bay. *Turkish Journal of Agriculture - Food Science and Technology, 9*(12), 2253–2259. https://doi.org/10.24925/turjaf.v9i12.2253-2259.4534
45. Silkina, A., Bazes, A., Mouget, J.-L., Bourgougnon, N. (2012). Macroalgal extracts and booster biocides as antifouling agents. *Marine Pollution Bulletin, 64*(10), 2039–2046. https://doi.org/10.1016/j.marpolbul.2012.06.028
46. Silva, A., Silva, S. A., Carpena, M., Garcia-Oliveira, P., Gullón, P., Barroso, M. F., Prieto, M. A., Simal-Gandara, J. (2020). Macroalgae as a source of valuable antimicrobial compounds. *Antibiotics, 9*(10), 642. https://doi.org/10.3390/antibiotics9100642
47. Taherkhani, A., Sharifi, A., Koubaa, M. (2024). Optimization of bioactive compound extraction from *Nizimuddinia zanardini*. *Foods, 13*(23), 3837. https://doi.org/10.3390/foods13233837
48. Tajbakhsh, S., et al. (2011). Antibacterial effect of *Cystoseira trinodis*. *Journal of Medicinal Plants Research, 5*(21), 5354–5358. https://doi.org/10.5897/JMPR.9000128
49. Thibaut, T., et al. (2014). Stability of *Cystoseira amentacea* in the Mediterranean Sea. *Marine Pollution Bulletin, 89*(1–2), 305–323. https://doi.org/10.1016/j.marpolbul.2014.09.043
50. Vimala, T., Poonghuzhali, T. V. (2017). Antimicrobial activity of *Hydroclathrus clathratus*. *Journal of Applied Pharmaceutical Science, 7*(4), 157–162. https://doi.org/10.7324/JAPS.2017.70423
51. Wang, Y., Xu, Z., Bach, S. J., McAllister, T. A. (2009). Sensitivity of *E. coli* to phlorotannins. *Asian-Australasian Journal of Animal Sciences, 22*(2), 238–245. https://doi.org/10.5713/ajas.2009.80213
52. Yoon, M., Kim, J. S., Um, M. Y. (2017). Extraction optimization for phlorotannin recovery from *Ecklonia cava*. *Journal of Aquatic Food Product Technology, 26*(7), 801–810. https://doi.org/10.1080/10498850.2017.1313348
53. Zheng, H., Zhao, Y., Guo, L. (2022). Phlorotannins from brown seaweeds. *Marine Drugs, 20*(12), 742.